Development of Polarization Optics for High-Resolution Vector Magnetic Field Measurements

Project Number: 96-20

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Purpose

This Center Director's Discretionary Fund (CDDF) effort involves development and characterization of nonpolarizing heat rejection filters and nonpolarizing optics as well as sensitive polarization analyzers to enable more sensitive measurements of the solar vector magnetic field.

Background

Scientists worldwide have a great interest in characterizing the Sun's magnetic field. Fortunately, this can be accomplished by using specialized instruments referred to as solar vector magnetographs. Iron ions in the solar atmosphere align to the Sun's magnetic field. These ions absorb light around 525-nanometer (green light) and 630.2-nanometer (red light) wavelengths. The polarization of this light, which is related to the magnetic field vector, must be measured by specialized telescopes and analyzers. The intensity of light at 656.3-nanometer wavelength is also measured.

A schematic for the experimental vector magnetograph (EXVM) located at the Marshall Center is shown in figure 39. This instrument is basically a Cassegrain telescope equipped with specialized filter coatings, transfer optics, a polarization analyzer, an image motion compensation tracker, and CCD detectors. The filter coatings are required to reject the tremendous solar light and heat load and be applied on a prefilter assembly in front of the telescope and/or on the primary or secondary mirror. Filter coatings deposited on mirror surfaces can also reduce

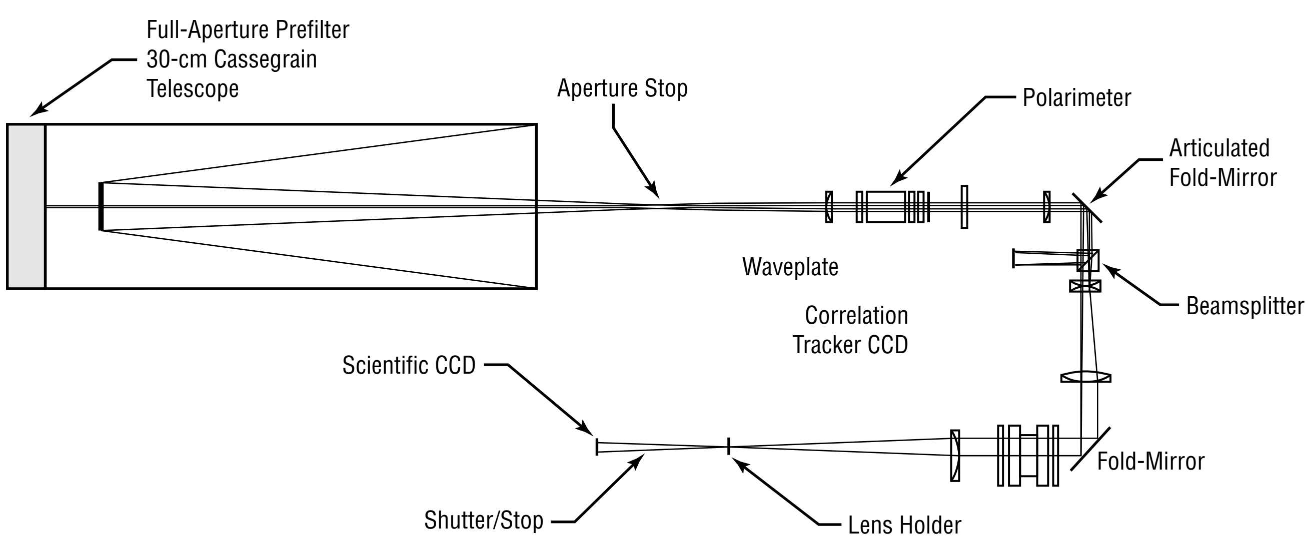

FIGURE 39.—Schematic of the EXVM magnetograph. The proposal will study the polarization properties of the entrance optics (full-aperture prefilter and telescope mirrors), the polarization sensitivity of the following optics (fold-mirrors and beamsplitter), and field of view errors in the polarimeter waveplate.

polarization introduced when the light reflects off the mirror surface at a nonnormal angle. A cube-type beamsplitter with specialized coatings is required to deflect a portion of the 656.3-nanometer wavelength light to the tracker while transmitting most of the remaining light to the polarization analyzer and CCD detector without altering the polarization of the analyzed light.

Approach

Filter coatings are designed by personnel in the Optics Branch at MSFC using Film Star, a commercial filter design software. The coating designs may consist of dielectric layers with varying indices of refraction, reflective metal layers, or combinations thereof. The coatings are applied by electron beam evaporation in a 30-inch Balzers BAK–760 Coating system which contains a Balzers GSM–420 optical monitor system. The CDDF effort also includes development of a large field-of-view waveplate that will minimize the instrumental modulation between the polarimeter and the final relay optics of the magnetograph.

Accomplishments

During the second year of the CDDF effort, there were several significant accomplishments. The investigators redesigned and produced a developmental cold mirror, or heat rejection coating, much like the one describe in the 1996 annual report. In addition, while searching for a simple metal-dielectric Fabry-Perot design to allow data to be taken quickly with the EXVM instrument at the 630.2-nanometer wavelength for Solar-B proposal, the principal investigator developed a new efficient design for the three-line prefilter to be developed for this CDDF effort. Development of this coating is currently underway. The full-aperture waveplates were designed, fabricated, and received from the vendor, but have not been tested.

The cold mirror coating was designed in order to reflect approximately 100 percent of the light at the measurement lines (525, 630.2, and 656.3 nanometers) while transmitting most of the infrared light through the mirror to an absorber or light trap. The developmental coating consisted of 32 layers of alternating high- and low- index dielectrics, in this case titanium dioxide and silicon dioxide. Spectral reflectivity measurements taken via a Perkin Elmer Lambda–19 spectrometer from 1-inch diameter coated glass substrates show that the high reflectance region covers the range from about 530 nanometers to about 680-nanometers wavelength. The theoretical design predicted a high reflectance from about 505 to about 670 nanometers; therefore, the experimental coating had a slightly narrower reflectance band and was slightly shifted to the red. The shift can be easily corrected. Spectral transmission measurements show better than 90 percent transmission for 725 nanometers to beyond 2-microns wavelength. About 4 percent transmission can be attributed to reflection from the uncoated back surface of the substrate. It should be noted that a telescope mirror coated in this manner would also introduce much less instrumental polarization into the measurements, thus the measurements will be far more accurate.

A theoretical prediction for the spectral transmission from an 11-layer metal-dielectric prefilter coating appears in figure 40. This coating is composed of alternating layers of silver and mixed-composite dielectric oxide material that

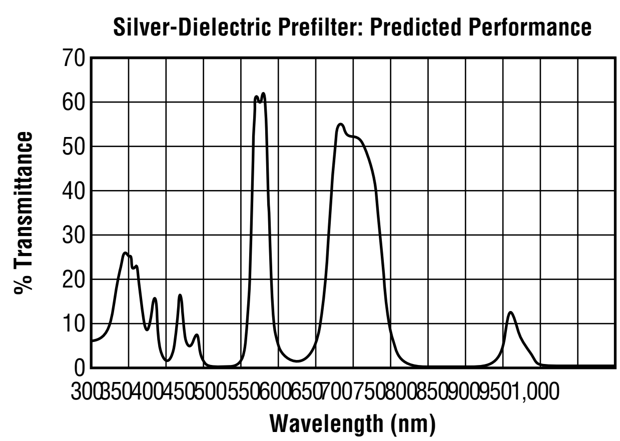

FIGURE 40.—Theoretical spectral transmission of a metal-dielectric prefilter designed to pass light at 525,630.2 and 656.3-nanometer wavelengths and to block sunlight at other wavelengths. The prefilter is designed for possible use in the EXVM instrument at Marshall Center.

was characterized in a study conducted by National Research Council Associate Dr. Naba K. Sahoo at MSFC. It is predicted that a successful attempt at depositing this coating will occur very soon.

Several significant problems regarding material properties had to be solved to enable the development of the coatings mentioned above. The selection of titanium dioxide, which is one of the highest refractive index coating materials that can be used in the visible region, was necessary to achieve the large bandwidth for the high reflectivity region of the cold mirror. That material commonly shows run-to-run variances in optical properties, so the use of an alternative material and alternative design may be necessary.

The thin silver layers used in the prefilter coating showed a local transmission minimum at around 7 to 8-nanometers thickness and followed by a local maximum at around 14 to 15-nanometers thickness. This effect has been previously reported.[1] As silver films in this thickness range are deposited, the material undergoes structural transitions from an island-type structure to a more continuous film. Multilayer coatings composed of silver films thinner than 14 to 15 nanometers show diminished transmission that cannot be easily modeled in the design software. Manual limits had to be enacted to exclude the use of silver layers thinner than about 14 to 15 nanometers. The use of the novel mixed-composite dielectric was necessary to achieve good adhesion to the silver, which should be deposited at room temperature.

Planned Future Work

During the early portion of the third year of the CDDF effort, the investigators plan to continue development of the prefilter coating. A full-scale development of the prefilter coating. A full-scale optic may be produced for the EXVM instrument. After the prefilter, development of the beamsplitter will continue. Any remaining effort will be spent on refinement of the cold mirror coatings. The investigators hope to identify more stable high index materials for use in the cold mirror.

Funding Summary ($k)

	FY96	FY97
Authorized by letter:	85.4	19.5
Total authorized:	104.9	
Committed, obligated, and costed by end of FY97:	101.0	
Carryover to FY98 for special materials:	3.9	

No direct contracts or grants.

Status of Investigation

Project approval date—October 17, 1995

Current estimated completion date—FY98

To be continued in FY98, with a carryover of 3.9k of FY98 funds.

Sennett, R.S.; and Scott, G.D.: *J. Optical Soc. Amer.*, 40, pp. 203–211, 1950.